MODULE INTEGRATED

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Breakout Session

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1. For grid connected systems, what electrical components are necessary between the module and the grid? What is the state-of-the-art efficiency for each of these components?

- Conventional DC bus to grid-tied inverter
  - 98.5 %
- AC modules direct to grid
  - 95-96 %
- DC/DC converters on modules with grid-tied inverter
  - 98.5% (MPP on each module)
- Most MOSFET based
- Depends on step-up and isolation requirement
- Isolation might not be necessary in the module

Q1 continuation:

- Hard switching versus soft switching trade-off depends on device type, reliability, voltage level
- Game-changer would be the integration, size of PCB, number of components
- Balance of system saving due to efficiency has large impact on cost.
- CEC efficiency takes into account various loading and illumination
- Higher frequency reduces size of components

2. What are the voltage and power metrics for the development of module integrated converters?

- 600V? 1000V?
- 250 W? 400 W?
- Module size can be changed to enable a very different system
- 220 - 350 W module standard. At low power efficiency is lower.
- Converter about 10% less than the module rating. You do not want to pay for the inverter when you get 300 W one hour in a year.
- Temperature rating might be higher than module if it's below 100 C range
- 600 V system rating, UL is allowing 1000 V behind the fence
- Similar issue as in automotive applications
- Module voltage 30 V Si, 100 V thin film, 240 V ac
- Residential has size limit that can be carried onto the roof
- Small modules (shingle size) will benefit most from module level converter

3. What is the maximum fraction of module weight that is reasonable to allocate to the converter?

- Target 2 lbs if it is on the module, 5 lbs @ 225 W if box on the rack
- Potting material is heavy and impacts reliability, keeps moisture out
- Metrics is better in terms of power density
- Peeling off encapsulation is a problem. Weight of carrying during installation and transportation is an issue. Can it survive snow, wind, thermal cycling?
- Various applications require different metrics, for example residential and commercial
- Thermal problem and size of components, potting influence the weight
- Reliability and communication are different than typical converter
- J-boxes are not optimal
- In docking approach only cost important. On the module reliable, with communication, easy install 20 cent would be a game-changer.

Reliability

- Frame integration reduces loading on the back of the module but causes other problems
- Weight on its own is not a deal killer. Do not want to trade off reliability and other factors.
- Reliability, power density, efficiency, cost, environmental bounds are trade-offs
- How do you make converter to integrate with the module at low cost?
- More value in residential side
- 25 year reliability on roof is very difficult
- Capacitors, optocouplers, magnetics, potting induced pressure are examples of reduced reliability
- SEB (single event burnout) in HV transistors due to neutron radiation
- Film capacitors cost more than electrolytic
- Surge protection influences reliability

4. Are there clear targets for the size of a module integrated converter? Size of a J-box?

5. **Module background: What are the typical losses associated with the bypass diode? How much does failure in the electrical interconnect contribute to overall failure of the module?**

6. What are the standard measures of module reliability? Under what test conditions. How do they differ for thin-film and crystalline Si modules?

7. What are the voltage and power metrics for the development of sub-module or cell-level converters?

- 2V? 100V?
- 5 W? 100W?

8. Are there alternatives to the bus interconnect architecture for thin-films that are compatible with sub-module integration?

9. Strategies for managing hot-spots due to partial shading and shunts?

10. How much greater enhancement in power yield is offered by employing sub-module conversion vs. module scale conversion?

11. Beyond enhanced power yield, what are the additional risks & benefits for sub-module power conversion:

- Risks: Overall decrease in module reliability? Additional manufacturing process for electronics integration (e.g. flip chip)?
- Benefits: Graceful degradation of module? Lower cost by co-packaging electronics and cells? Lower cost, voltage electronics?

Technology Impact

- What technology can have the greatest impact on the module converter?
  - AC module
    - 30 instead of 300 components, 5 times smaller, low cost
    - More advanced technology, high frequency, simple digital controller
    - Reduce from $200 to $20
    - Small penetration now $1/W price. It would eliminate central inverters.
  - Shading is a big opportunity. What is a benefit of the number of modules per converter? Some applications are enabled by module level converter.
  - What intelligence can be imbedded in the module converter?
  - Developing ecosystem enabling new solar converters
  - Separate AC modules, sub-module integrated converter
  - Multiple components need to be improved to make impact on PV converters
  - Residential market can have better opportunity with improved reliability
  - One company trying to add switches at cell level

- Thin Film Module Converters
  - Is cell level converter for thin film module a game-changer?
  - Difficult to integrate cell level converter
  - How much benefit? Is challenge fundamental?
  - Power electronics is only one way to address problem
  - Improving manufacturing is another solution
  - Best companies have no problem with uniformity
  - State of the art tracking is flat versus power level
  - Magnetics, capacitive losses, housekeeping adds several % cost to the inverter. Cost would be lower if only designed for peak power.
- Concentrated PV systems use one diode for each cell
  - MPP algorithms have to be different depending on the type of cell
  - Higher fill factors

- Microinverters
  - Reliability spots
    - Solder joints, capacitors, magnetics, potting material
  - Size is a differentiator for microinverters
  - Volumes 60 GW total, but on-module converters are not significant
  - Module makers are driving force in on-module converters
  - Docking consortium is transformational for the market
  - Microinverters are developed by start-ups

Sub-Module Converter Summary

- Efficiency: state of the art
  - Microinverters 95-96 %
  - DC-DC > 98 %
- Form Factor
  - Smaller and lighter is always better (2 lbs.?)
  - Not as important as cost and reliability
- Reliability
  - Converter reliability > module reliability
- Transformational Technology
  - AC modules: 10x reduction in cost and size
  - Submodule converters (cell or string level)
    - Benefits not completely defined
    - Higher technical barrier